

Heavy ion Physics with ALICE

MERCEDES LÓPEZ NORIEGA FOR THE ALICE COLLABORATION

Institut de Physique Nucléaire d'Orsay

Abstract

ALICE will study the physics of the strongly interacting matter produced in nucleus-nucleus collisions at the LHC where the formation of the Quark Gluon Plasma is expected. The experimental setup, the capabilities of the detector, and a few selected heavy-ion topics will be presented and discussed.

Quantum Chromodynamics (QCD) predicts a transition from a stable state of matter formed by hadrons to a plasma of deconfined quarks and gluons at sufficiently high energy density where the average distance between particles becomes so small that confinement disappears. Ultrarelativistic heavy ion collisions are the way of reaching energy densities about the critical one to create this Quark Gluon Plasma (QGP) in the laboratory. This should allow us to better understand the strong interaction by studying the properties of the phase transition and the hadron formation.

This kind of collisions will soon take place at the Large Hadron Collider (LHC) located at CERN. Heavy ion beams will collide with a maximum center-of-mass energy of 5.5 ATeV in the case of PbPb collisions. This implies an increase on energy of about a factor of 30 with respect to the highest energy collisions that have taken place until now. As a consequence the energy density reached in these collisions is expected to be between 3 and 10 times larger.

1 ALICE

ALICE, A Large Ion Collider Experiment, is the only LHC experiment dedicated to the study of heavy ion collisions [1]. It consists of different parts.

The central part is located around the collision point and inside a solenoidal magnet that will provide a magnetic field up to 0.5 T. Several detectors will assure the reconstruction of particles in the rapidity range $|y| < 0.9$ with full azimuthal coverage. Those detectors are, as seen by a particle traveling out from the interaction point:

- ITS, Inner Tracking System, with an inner radius of 4 cm and an outer radius of 40 cm, it is formed by three subsystems of two layers each: a silicon pixel, a silicon drift, and a silicon strip detector. It will allow the 3-D reconstruction of the collision primary vertex, secondary vertex finding, and particle identification via dE/dx .
- TPC, Time Projection Chamber, which is the main tracking detector for charged particles in the central barrel of ALICE. It has an inner radius of 0.9 m, an outer radius of 2.5 m, and a length of 5.1 m. It is optimized for large track densities (up to $dN/dy = 8000$) and it will allow track finding, momentum measurements, and charged particle identification via dE/dx .
- TRD, Transition Radiation Detector, consists of 18 longitudinal supermodules (6 ready for the first run, limiting the azimuthal acceptance), 6 radial layers and 5 stacks along the beam axis. Its prime function is the identification of electrons; it will also provide fast triggering.
- TOF, Time Of Flight, consists of 18 longitudinal modules and 5 modules along the beam axis. It will allow charged particle identification.

Also in the central part there are some detectors with smaller coverage. The HMPID, High Momentum Particle IDentification, which provides particle identification for particles in the 1 to 6 GeV/c momentum range. The PhoS, Photon Spectrometer, and the EMCal, ElectroMagnetic Calorimeter, for photon and neutral particle identification.

In the pseudorapidity region $-4.0 < \eta < -2.5$ there is a Muon Spectrometer designed to detect muons at backward rapidity with a mass resolution of 1% at 10 GeV/c². It consists of a large front absorber located very close to the interaction point to minimize contributions from hadrons and photons; 5 tracking stations of two detectors planes each to reconstruct the muons; 2

trigger stations behind a muon filter that provides fast trigger capabilities; and a dipole magnet with a field integral of 3 Tm.

There is also a set of forward detectors close to the LHC beam. The T0 for event triggering and tagging; the FMD that provides multiplicity information over $-3.4 < \eta < -1.7$ and $1.7 < \eta < 5.0$; ZDCs for spectator nucleons and protons; the V0 that provides triggering and luminosity information; and the PMD to provide information on photon production at forward rapidities.

These detectors, and combining several identification techniques, will allow the identification of particles over a wide rapidity range up to large momentum values.

2 Heavy-ion physics with ALICE

When two heavy-ion nuclei collide, there is a pre-equilibrium state in which each nucleon scatters several times and partons are liberated. These quarks and gluons thermalize by re-scattering resulting in a thermalized QGP. The system then expands collectively and cools down to temperatures around the critical temperature when hadrons are formed. The hadrons interact inelastically until the system reaches what is known as the chemical freeze-out and this kind of interactions stops. The system keeps expanding and eventually it is diluted enough that the interactions between hadrons stop, the system undergoes a thermal freeze-out, and hadrons fly off to our detectors. Several observables allow us to study the created medium and the different stages of the evolution of the system. In this section I will describe some of these observables and show the expected performance of ALICE.

2.1 Soft physics: particle ratios and elliptic flow

We call “soft physics” to the observables dominated by low p_T particles, *i.e.* the p_T region below 3 or 4 GeV/c.

From the chemical composition of the system and its comparison to equilibrium and non-equilibrium statistical model predictions we will be able to extract the freeze-out parameters (chemical freeze-out temperature and baryon-chemical potential) and the degree of equilibration of the system [2, 3]. In particular, non-identical particle ratios with strange baryon involved are very sensitive to the equilibrium hypothesis. The distinction between equilibrium and non-equilibrium scenarios should be possible in ALICE.

The system created in a non-central collision has an initial azimuthal anisotropy in the coordinate space. The multiple interactions among the

constituents will generate a pressure gradient that will transform this initial coordinate space anisotropy into a momentum space anisotropy. The magnitude of v_2 , the second Fourier coefficient of the azimuthal anisotropy of particle production, and its p_T dependence allow for the extraction of the thermal freeze-out temperature and transverse flow velocity. The question whether v_2 has reached the hydrodynamical limit at RHIC, reflecting a perfect fluid behavior, is still highly debated. According to several predictions one should be closer to ideal hydrodynamics at the LHC while a significant increase on v_2 is still possible. In ALICE, different methods will be applied to extract v_2 .

2.2 Hard probes

The domination of hard processes, those coming from initial hard scattering of nucleon constituents, in the early stage of the collision will have as a consequence that very hard probes will be copiously produced and therefore event-by-event jet reconstruction and jet-quenching studies will be possible, and heavy flavors like beauty will become accessible.

2.2.1 High- p_T physics

The large transverse momentum partons generated in the initial hard scattering of nucleon constituents will fragment to create a high energy cluster of particles, a jet. These partons will also travel through what is predicted to be a dense colored medium and there they are expected to lose energy via medium induced gluon radiation [4, 5]. The magnitude of this energy loss is predicted to depend strongly on the gluon density of the medium. Therefore, measurements on how quenching changes the structure of the jet and its fragmentation function will reveal information about the QCD medium created in these collisions.

A convenient way of studying how the medium modifies the jet structure is through the fragmentation function, represented in Fig. 1 by the distribution of $\xi = \ln(E_T^{\text{jet}}/p)$. The particular shape of the distribution is called the hump-backed plateau [6]. Medium induced energy loss distorts the shape of the plateau in a characteristic way. Figure 1 shows the hump-backed plateau for 100 GeV jets compared to the contribution from the background underlying event for different cone sizes R (where the jet energy is contained) as seen in simulations in ALICE. The region $\xi < 4$ corresponds to particles with p_T larger than 1.8 and therefore the leading particle remanent can be observed with $S/B > 0.1$. Particles from medium-induced gluon radiation

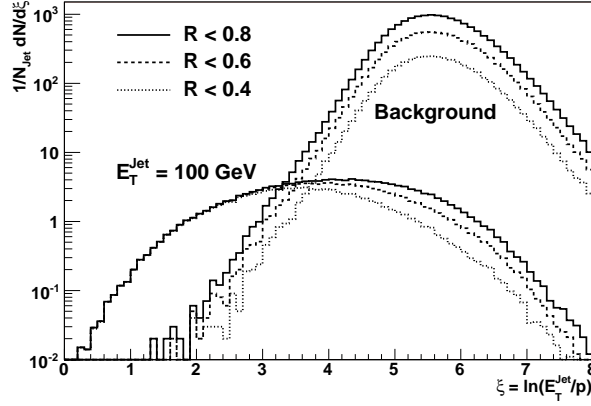


Figure 1: The hump-backed plateau for 100 GeV jets compared to the contribution from the background of the underlying event for different cone sizes R .

are expected to show up mostly in the region $4 < \xi < 6$ where the S/B is of the order of 10^{-2} .

One very attractive method to obtain an unbiased measurement of the original parton energy is to tag jets with prompt photons emitted in the direction opposite to the jet direction. The dominant processes for such events are Compton scattering and annihilation and they dominate the photon spectrum at $p_T > 10$ GeV/c. This technique helps to localize the jet. The measured photon energy is equal to that of the parton before energy loss because photons emerge from the medium almost unaltered. ALICE will tag jets with photons measured in the PhoS or the EMCAL and will study the parton in-medium-modification through the fragmentation function.

2.2.2 Heavy quarks: open heavy flavor and quarkonia

Heavy quarks, charm and beauty, will be abundantly produced in heavy-ion collisions at the LHC, and both the production of open heavy flavor and quarkonia will probe the strongly interacting medium created in these collisions. Heavy flavor will also probe the gluon small Bjorken- x domain where the gluon density is expected to be close to saturation leading to modifications of the particle production rate.

The energy loss at the partonic level in heavy-ion collisions is expected to depend on the color charge (stronger for gluons than for quarks due to the higher gluon color charge) and on the mass (weaker for heavy than for

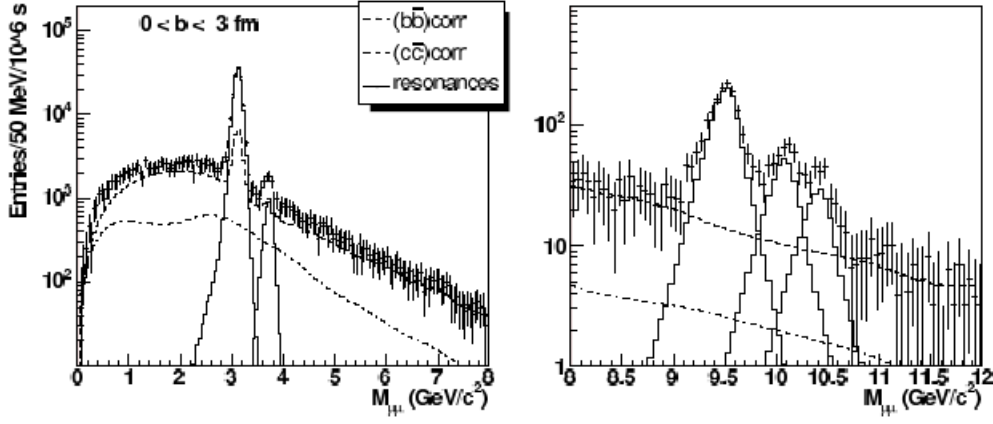


Figure 2: Dimuon invariant mass spectra in the J/ψ mass region (left) and in the Υ mass region (right) after the subtraction of the uncorrelated background in central PbPb collisions.

light quarks due to the dead cone effect) [7, 8]. One would therefore expect less high- p_T quenching for heavy flavor particles that originate from heavy quark jets than for light flavor particles that are created in both gluons and (mostly) light quark jets. In ALICE we will be able to separate the production of charm and beauty hadrons and we will be able to test the energy loss models.

Quarkonia are bound states of heavy quarks. It has been predicted that if a deconfined medium was created in heavy-ion collisions then a suppression in the J/ψ (a $c\bar{c}$ bound state) production would be observed [9]. This is due to the fact that in a deconfined medium the attraction between heavy quarks and antiquarks is reduced due to the color screening induced by lighter quarks. Results from previous experiments at SPS and RHIC are not conclusive and puzzling. It is expected that the measurement of the J/ψ yield in PbPb collisions at 5.5 TeV will finally disentangle between the different suppression/regeneration scenarios. Models that include regeneration predict an enhancement of J/ψ production at the LHC due to the large number of $c\bar{c}$ pairs produced. If sequential screening is the right explanation, J/ψ will finally melt at the LHC. But any of these scenarios would imply deconfinement of the created system.

Figure 2 shows the expected ALICE performance for the measurement of the dimuon spectrum in the muon arm for one month of PbPb run. ALICE will be able to measure J/ψ with high statistics in the p_T range 0–20 GeV/c

and therefore we will be able to measure the predicted effects.

3 Conclusion

ALICE is ready for data taking and it is well suited to measure global event properties on a wide range in PbPb and pp collisions. The nature of the bulk will be studied via processes like composition and collective expansion. ALICE will reconstruct jets in heavy ion collisions to study the properties of the dense created medium. Charm and beauty production will be studied and the upilon family will be accessible for the first time in AA collisions.

References

- [1] ALICE Collaboration, J. Phys. G: Nucl. Part. Phys. **30** (2004) 1517
- [2] P. Braun-Munzinger *et al.*, Phys. Lett.B**518** (2001) 41.
- [3] J. Rafelski and J. Letessier, Eur. Phys. J. C**45** (2006) 61.
- [4] X.-N. Wang and M. Gyulassy, Nucl. Phys. B**420** (1994) 583.
- [5] X.-N. Wang, M. Gyulassy and M. Plümer, Phys. Rev. D**51** (1995) 3436.
- [6] N. Borghini and U. A. Wiedemann, CERN-PH-TH-2005-100, hep-ph/0506218 (2005).
- [7] R. Baier *et al.*, Nucl. Phys. B**483** (1997) 291.
- [8] Yu. L. dokshitzer and D. E. Kharzeev, Phys. Lett. B**519** (2001) 199.
- [9] T. Matsui and H. Satz, Phys. Lett. B**178** (1986) 416.